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APPLICANT'S: Tetsuya OTOSAKA, et al.

FOR: OPTICAL FIBER PREFORM, METHOD FOR MANUFACTURING THEREOF, AND OPTICAL FIBER OBTAINED BY DRAWING THEREOF

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OPTICAL FIBER PREFORM, METHOD FOR MANUFACTURING THEREOF, AND OPTICAL FIBER OBTAINED BY DRAWING THEREOF

The present application claims priority from a Japanese
Patent Application No. 2002-230380 filed on August 7, 2002, the
contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to an optical fiber preform
with a small transmission loss of light at wavelength of 1385nm
and small rise of the transmission loss caused by a hydroxy (OH)
group in case of being exposed to hydrogen atmosphere, a method
for manufacturing the optical fiber preform, and an optical fiber
obtained by drawing the optical fiber preform.

Description of the Related Art

Fig. 1 shows an example of the configuration of a conventional
optical fiber preform sintering apparatus 100. The sintering
apparatus 100 has a container 14, a heater 22, a gas introduction
pipe 24, and a drive source 16. The container 14 is made from
silica glass. A heater 22 is arranged around the container 14
to heat the container 14.

The gas introduction pipe 24 is connected to the bottom part
of the container 14, and the mixed gas, which contains inert gas
such as helium (He) gas and dehydration-reaction-gas such as
chlorine (Cl_2) gas, is introduced into the container 14 through
the gas introduction pipe 24.

An exhaust pipe 20 is connected to the top part of the container
14, and the mixed gas which travels through the container 14 from

the bottom part of the container 14 is discharged from the exhaust pipe 20. The drive source 16 is provided in the upper part of the sintering apparatus 100. The drive source 16 is connected to a core rod 10.

5

The optical fiber preform 12 is formed around the circumference of the core rod 10 by such as VAD method before the dehydration process. The drive source 16 inserts the preform 12 into the container 14 by descending the core rod 10 into the container

10   14. The container 14 is filled with the atmosphere of the mixed gas, which flowed from the gas introduction pipe 24, and the circumference of the container 14 is heated by the heater 22. Therefore, the preform 12 inserted into the container 14 is heated under a mixed gas atmosphere to be dehydrated and sintered.

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Fig. 2 shows relationship between a transmission loss and wavelength in a conventional general single mode optical fiber. Wavelength of light used in communication is mainly about 1300 nm or about 1550 nm because an inexpensive semiconductor laser

20   can be used. As WDM (Wavelength Division Multiplexing) technology advances, light at wavelength band from 1300nm to 1600nm needs to be used in order to raise data-transmission capacity.

However, as shown in Fig. 2, the transmission loss in a general

25   optical fiber rises sharply in wavelength of about 1385nm. As the transmission loss becomes greater, the regenerator for amplifying and regenerating light needs to be added for a long distance transmission, which results in that cost of the whole transmission or communication system rises.

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Accordingly, it is necessary to suppress an abrupt increase of the transmission loss at wavelength of about 1385 nm.

In addition, as shown in Fig.2, a difference between a peak value of the transmission loss at wavelength of about 1385nm and a value of the transmission loss in a case of decreasing gradually as shown by a broken line is defined as an OH peak hereinafter. For example, the OH peak shown in Fig.2 is about 0.06dB/km. The sharp rise or abrupt increase of the transmission loss at wavelength of about 1385nm, i.e. the OH peak is caused by vibration of the OH group contained in the optical fiber and absorbing light of that wavelength. In order to decrease the OH group in the optical fiber, it is necessary to decrease the OH group in the preform which is a base material of the optical fiber.

Furthermore, even if the OH peak in the optical fiber just after drawing is sufficiently small, there is a possibility that the OH peak rises by hydrogen diffusing in the optical fiber, and reacting to a defect in a glass of the optical fiber, and then generating the OH group, if the optical fiber is exposed to hydrogen atmosphere for some reasons.

In Fig.3, a dotted line shows a spectrum of the transmission loss in case that the optical fiber, the OH peak of which is sufficiently small as shown by a solid line, is exposed to atmosphere of 1% hydrogen for four days. Fig.3 shows a rise of 0.1dB/km of the OH peak at wavelength of about 1385nm. The OH peak at wavelength of about 1240nm is caused by hydrogen diffusing in the optical fiber. The OH peak disappears if the optical fiber is exposed to atmospheric air for a while and hydrogen is removed from the optical fiber. However, the rise of the OH peak at wavelength of about 1385nm is irreversible and does not decrease. Therefore, the defect that causes the rise of the OH peak in the optical fiber needs to be reduced sufficiently.

SUMMARY OF THE INVENTION

Therefore, it is an object of the present invention to provide
5   an optical fiber preform, a method for manufacturing thereof, and
an optical fiber obtained by drawing thereof, which is capable
of overcoming the above drawbacks accompanying the conventional
art.   The above and other objects can be achieved by combinations
described in the independent claims.   The dependent claims define
10   further advantageous and exemplary combinations of the present
invention.

According to the first aspect of the present invention,
assuming T_s to be a temperature at which the maximum value
15   V_0[log(poise)] of a radial viscosity distribution of the optical
fiber in an inside area is 7.60[log(poise)], in the inside and
an outside area equivalent to two times of mode field diameter,
in which light at wavelength of about 1385nm propagates in the
optical fiber obtained by drawing the preform, the preform of the
20   present invention is that the maximum value V_0[log(poise)] of radial
viscosity distribution of the optical fiber is greater than
7.60[log(poise)] at the T_s.   In this case, the maximum value
V_0[log(poise)] of viscosity distribution may be greater than
7.90[log(poise)].

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The prefrom comprises a multi layer structure of which an
outside area of the clad has more than two layers and has a high
viscosity clad layer of which at least at one temperature viscosity
is greater than viscosity of the inner clad layer of the most inside
30   area in the outside area at the temperature T_s, among the clad
layers outside the inner clad layer.   Preferably an outside low
viscosity clad layer of which viscosity is smaller than V_0 at the

temperature T_s, is the most outside of the clad. In addition, viscosity of surface of the preform at the temperature T_s is preferably lower than V_0.

5 On the other hand, the clad of the outside area may be comprised of two layers, that is, an inner clad layer and a high viscosity clad layer.

A synthetic quartz glass may be used as the inner clad layer, and a quartz glass, for example such as a native quartz or a crystallization synthetic quartz glass, containing crystal type silica may be used as the high viscosity clad layer.

Furthermore the preform may be manufactured by using the synthetic quartz glass having the lower viscosity than a pure synthetic quartz glass by doping at least with one dopant among chlorine, germanium, fluorine, and phosphorus as the inner clad layer and using the synthetic quartz glass having higher viscosity than the inner clad layer by not doping or doping with small amount of dopant as the high viscosity clad layer. In addition, a portion containing at least the core and the inner clad layer may be formed by VAD method, OVD method, MCVD method, and PCVD method, or by appropriate combination of them.

25 According to another aspect of the invention, a method for manufacturing the preform includes steps of covering circumference of the rod at least the core and the inner clad layer with a tube containing at least the high viscosity clad layer, and unifying the rod and the tube by heating and contracting the tube or by heating glass grain while depositing the glass grain which forms the high viscosity clad layer. In addition, plasma flame is preferably used at this heating.

The preform may be manufactured by forming a porous preform by depositing glass particles generated by a flame hydrolysis of a glass crude material containing silicon on the circumference

5   of the rod comprising at least the core and the inner clad layer, and forming the high viscosity clad layer by vitrifying the porous preform at temperature between 1400 and 1600 °C after dehydrating the porous preform in atmosphere containing dehydration gas at temperature range between 900 and 1200 °C. In this case, chlorine

10   gas is used as the dehydration gas.

Furthermore the method for manufacturing preform comprises covering circumference of the rod comprising at least the core, the inner clad layer, and the high viscosity clad layer with the

15   tube containing at least the outside low viscosity clad layer, and unifying the rod and the tube by heating and contracting the tube. The preform may be manufactured by forming the outside low viscosity clad layer by depositing glass particles generated by flame hydrolysis of glass crude material containing silicon on

20   the circumference of the rod.

Furthermore the method for manufacturing the preform may comprise covering circumference of the rod comprising at least the core and the inner clad layer with the tube containing the

25   high viscosity clad layer, and unifying the rod and the tube by heating and contracting the tube, while forming the outside low viscosity clad layer by depositing glass particles generated by flame hydrolysis of glass crude material containing silicon. The method may comprise covering circumference of the rod comprising

30   at least the core and the inner clad layer with the tube containing at least the high viscosity clad layer and the outside low viscosity

clad layer, and unifying the rod and the tube by heating and contracting the tube.

The optical fiber of which the transmission loss at
5   wavelength of 1385nm is equal to or less than 0.35dB/km, preferably equal to or less than 0.30dB/km, is obtained by heating and drawing the above-mentioned preform.

The transmission loss of the optical fiber at wavelength
10 of 1385nm is equal to or less than 0.35dB/km in case that the fiber is exposed to atmosphere containing 1% hydrogen for four days, and does not substantially change compared with the transmission loss at wavelength of 1385nm before exposed to the atmosphere.

15 The summary of the invention does not necessarily describe all necessary features of the present invention. The present invention may also be a sub-combination of the features described above. The above and other features and advantages of the present invention will become more apparent from the following description
20 of the embodiments taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

25 Fig. 1 is a partially cut-out view showing an example of the conventional configuration of an optical fiber preform sintering apparatus.

Fig. 2 is a graphic chart showing relationship between the transmission loss and wavelength in a general single mode optical
30 fiber.

Fig. 3 is a graphic chart showing relationship between the transmission loss and wavelength of the fiber being exposed to hydrogen atmosphere.

Fig. 4 shows an example of a preform 200 manufactured by the sintering apparatus to which the invention is applied.

Fig. 5 is a graphic chart showing relationship between difference of relative index of refraction of the preform and radial viscosity distribution at the temperature T_s in examples 1-7 of the present invention and a comparative example 4.

Fig. 6 is a graphic chart showing relationship between difference of relative index of refraction and radial viscosity distribution at the temperature T_s in the preform as examples 1-3.

Fig. 7 is a graphic chart showing relationship between difference of relative index of refraction of the preform and radial viscosity distribution at the temperature T_s as an example 8 of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The invention will now be described based on the preferred embodiments, which do not intend to limit the scope of the present invention, but exemplify the invention. All of the features and the combinations thereof described in the embodiment are not necessarily essential to the invention.

Fig. 4 shows an example of a preform 200 manufactured by the sintering apparatus 100 shown in Fig. 1. A preform 200 has a cylindrical core 10, made from quartz doped with germanium, and a first, inner clad 32, made from quartz, formed around the outside surface of the core 10.

A second, outer clad 34 may be formed around the outside

surface of the preform 200 to increase the thickness of the clad 32. The content of the OH group in the preform 200 is substantially 0.8 ppb or less. Moreover, the amount of projection of the OH peak in the curve that shows the transmission loss of the light

5 of the optical fiber, which is obtained by drawing the preform 200, is substantially 0.05 dB/km or less. Therefore, the optical fiber obtained from the preform 200 can be used for light transmission in the wavelength band from 1300 nm to 1600 nm.

10 According to the present invention, even if the optical fiber pulled from the preform is exposed to hydrogen atmosphere, the rise of the transmission loss (OH peak) at wavelength of 1385nm is suppressed by controlling radial viscosity distribution around softening temperature of the preform.

15

If the optical fiber is exposed to hydrogen atmosphere, hydrogen diffuses into the optical fiber, and then hydrogen reacts with the defect existing in the glass of the optical fiber, and then the OH peak rises due to the generation of the OH group.

20

Such a defect does not exist in the preform at the beginning, but many of which are generated during the drawing process with rapid change of the shape under the temperature of about 2000 °C. If the conventional preform is pulled, sensitivity to hydrogen

25 of the OH peak changes greatly according to the condition of the drawing process.

On the other hand, the preform of the present invention is that the maximum value V_0[log(poise)] of radial viscosity

30 distribution of the optical fiber is greater than 7.60[log(poise)] at the temperature T_s, defined as temperature at which the maximum value V_0[log(poise)] of radial viscosity distribution of the

optical fiber in an inside area is 7.60[log(poise)] in an inside
and an outside area equivalent to two times of mode field diameter,
in which light at wavelength of 1385nm propagates in the optical
fiber obtained by drawing the preform.

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Therefore the optical fiber obtained by drawing the preform
of the present invention has a superior characteristic that rise
of the OH peak is suppressed remarkably without depending on the
condition of the drawing process.

10

This temperature T_s is about 1600 °C in the case of a normal
single mode fiber in which quartz glass doped with germanium (Ge),
is used as a core.

15　　　　When the preform manufactured in this manner is drawn, since
viscosity of the outside area is relatively greater than the inside
area, drawing stress at the inside area is smaller than drawing
stress at the outside area, so generation of the defect in the
inside area is suppressed.　On the other hand, although many defects
20　are generated at the outside area, since the majority of the light
propagates through the inside area, the rise of the OH peak is
hardly recognized, even if hydrogen diffuses into the optical
fiber.

25　　　　Generally in the case of the single mode fiber of which the
core is doped with Ge, unless the clad is doped with a dopant to
adjust a viscosity, since the viscosity of the clad becomes greater
than a viscosity of the core and generally composition is
substantially constant in a radial direction, the above mentioned
30　viscosity distribution is not obtainable.

According to the present invention, the above-mentioned viscosity distribution is achieved by having more than two layers as the clad in the outside area, lowering viscosity of the inner clad layer of the most inside layer in the outside area, and forming

5 a high viscosity layer by heightening viscosity of at least one of the other clad layers. While the fiber normally has two layers including an inner clad layer of low viscosity and a high viscosity clad layer, it may have three layers as mentioned below according to viscosity and thickness of the high viscosity clad layer.

10

In the inside area equivalent to two times of mode field diameter, maximum value V_0[log(poise)] of radial viscosity distribution outside the inside area, is preferably equal to or more than 7.90[log(poise)] at the temperature T_s at which the

15 maximum value of radial viscosity distribution is 7.60[log(poise)], so that the desired effect of the invention can be realized.

The clad has two layers structure comprising the inner clad

20 layer and the high viscosity clad, if diameter of the inner clad layer is less than 80% of outer diameter of the preform and V_0=7.90, rise of the OH peak is equal to or less than about 0.03dB/km.

Although outer diameter of the inner clad is preferably small

25 to suppress rise of the OH peak due to hydrogen, in case that a glass used for the high viscosity clad layer is material of which the possibility of increasing the transmission loss remarkably is high like a native quartz glass, unless the outer diameter is sufficiently large (about six times of the mode field diameter),

30 the initial loss may be large.

In the case of for example manufacturing the preform comprising a synthetic quartz glass inside of the preform and a native quartz glass outside of the preform, an upper limit of V_0 is about 9.0. On the other hand, in the case of doping glass of

5   the inside area with a large amount of dopant, an upper limit of V_0 can be larger than 9.0, and influences such as the transmission loss caused by doping, can not be defined sweepingly because the influence largely depends on the composition.

10   In case of the most outside layer being the high viscosity clad layer, a problem that strength of the optical fiber becomes lower, may occur by residual stress of the surface of the optical fiber changing to tensile stress. For example if heightening V_0 and thinning the high viscosity clad layer, rise of the OH peak

15   and the initial loss are advantageously suppressed, but residual tensile stress of the surface of the optical fiber becomes large and snapping of the fiber can be caused during the drawing, winging back, or proof test.

20   To reduce this kind of residual tensile stress of the surface of the optical fiber, residual tensile stress of the surface can be reduced or be changed to compressive stress, and strength of the optical fiber can be improved by adding an outside low viscosity clad layer of which viscosity is lower than the high viscosity

25   clad layer to outside of the high viscosity clad layer. If viscosity of the outside low viscosity clad layer at the temperature T_s is 7.60[log(poise)] equal to viscosity of the inner clad layer roughly, strength of the optical fiber is improved sufficiently.

30   Viscosity can be distributed in radial direction of the preform by changing quality of glass material composing the inner clad layer and the high viscosity clad layer.

The synthetic quartz glass used for the preform for the conventional optical fiber includes amorphous structure manufactured by oxidizing or hydrolyzing by flame glass crude material gas such as silicon tetrachloride. On the other hand, in the native quartz glass manufactured by heating and fusing the native quartz, there are many microcrystals of cristobalite type helix originating from the nature of quartz and quartz type helix that cristobalite type is dislocated in the amorphous structure. Because these microcrystals suppress flow of glass, the native quartz glass has higher viscosity than the synthetic quartz glass.

A crystallization quartz glass manufactured by depositing microcrystal in the synthetic quartz glass has higher viscosity than a conventional synthetic quartz glass. In addition, viscosity of the crystallization quartz glass can be lower easily by doping the synthetic quartz glass with many kind of dopant. Generally, even if the transmission loss rises by doped with a dopant due to absorption of ultraviolet rays, infrared rays, or the like, the dopant such as chlorine, germanium, fluorine, phosphorus, and the like does not cause so large rise of the loss at wavelength range between 1300 to 1600nm which is normally used for the optical fiber communication, so these dopant are preferably used.

In these dopant, by suppressing the defects being generated in the portion that light propagates in the optical fiber by heightening inside viscosity and lowering outside viscosity by using glasses having different viscosity, rise of the OH peak at which the optical fiber exposed to hydrogen atmosphere is remarkably suppressed.

To manufacture the core and the clad around the core, conventional VAD method, OVD method, MCVD method, and PCVD method, or by the combination of them can be adopted. Because (1) high purity is needed due to influence on the large transmission loss and (2) viscosity is needed to be low preferably, the synthetic quartz glass or the synthetic quartz glass doped with a dopant to lower viscosity is preferably used for the inner clad layer, and the inner clad layer can be formed as an extension of clad portion of the inside area.

The first method covering outside of a rod containing the core portion and the inner clad layer with the high viscosity clad layer having high viscosity comprises unifying the rod and a tube by placing the rod in the tube containing the high viscosity clad layer and contracting the rod by heating form outside. In this case, oxyhydrogen flame, electric furnace, plasma torch, or the like can be used as a heating source.

The second method comprises unifying the rod and glass grain by heating while depositing on the circumference of the above-mentioned rod by scattering the glass grain composing the high viscosity clad layer. In this case, plasma torch is preferably used as the heating source.

The third method covering the rod with the high viscosity clad layer is OVD method that includes forming the porous preform by depositing glass particles manufactured by flame hydrolysis of the glass crude material containing silicon on the circumference of the above-mentioned rod, and a dehydrating porous preform at the temperature range between 900 and 1200 °C in the atmosphere containing dehydration gas such as chlorine or the like, and then forming the high viscosity clad layer by vitrifying in the

atmosphere at the temperature between 1400 and 1600 °C. In this case, because the high viscosity clad layer changes into the synthetic quartz glass, the inner clad layer needs to be doped with dopant to lower its viscosity.

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The first method covering outside of the high viscosity clad layer with the outside low viscosity clad layer includes covering the circumference of the rod with the tube containing at least the outside low viscosity clad layer, and unifying the rod and

10 the tube by heating and contracting the tube.

The second method covering outside of the high viscosity clad layer with the outside low viscosity clad layer includes depositing glass particles manufactured by flame hydrolysis of

15 glass crude material containing silicon on the circumference of the rod containing the high viscosity clad layer.

The first method covering outside of the inner clad layer with the high viscosity clad layer and the outside low viscosity

20 clad layer, comprises covering the circumference of the rod comprising at least the core and the inner clad layer with the tube containing the high viscosity clad layer, and then covering the tube with the outside low viscosity clad layer by depositing glass particles manufactured by flame hydrolysis of glass crude

25 material containing silicon, while unifying the rod and the tube by heating and contracting the tube.

Furthermore the first method covering outside of the inner clad layer with the high viscosity clad layer and the outside low

30 viscosity clad layer, comprises covering the circumference of the rod comprising at least the core and the inner clad layer with the tube containing at least the high viscosity clad layer and

the outside low viscosity clad layer, and unifying the rod and the tube by heating and contracting the tube.

[Example 1]

5   An step index type single mode optical fiber as shown in Fig.5, of which outer diameter is 125μm, difference of relative index of refraction is 0.34%, mode field diameter at wavelength of 1385nm is 10μm, is manufactured by forming clad of periphery of the core in inside area with glass which has the same composition 10   as the inner clad layer in outside area, and drawing the preform having two layers of the inner clad layer and the high viscosity clad layer in outside area at drawing speed of 800m/min and drawing tension of 1.4N.

15   Of the optical fiber, an outer diameter of the inner clad layer is 100μm in terms of optical fiber diameter, thickness of the high viscosity clad layer is 12.5μm in terms of optical fiber, viscosity V_0 of the high viscosity clad layer at the temperature T_s is 7.9 [log(poise)]. Rise of the OH peak of 0.03dB/km is measured, 20   after this optical fiber is exposed to atmosphere containing 1% hydrogen for four days.

Figs.5 to 7 are graphs showing relationships of differences of relative index of refraction and radial viscosity distribution 25   at the temperature T_s of the preform, of which upper row is relationship of difference of relative index of refraction and structure, and the lower is relationship of viscosity and optical fiber equivalent radius.

30   [Example 2]

The step index type single mode optical fiber as shown in Fig.5, of which outer diameter is 125μm, difference of relative

index of refraction is 0.34%, mode field diameter at wavelength
of 1385nm is 10μm, is manufactured by forming clad of periphery
of the core in the inside area with glass which has the same
composition as the inner clad layer in outside area, and drawing
5 the preform having two layers of the inner clad layer and the high
viscosity clad layer in outside area at drawing speed of 800m/min
and drawing tension of 1.4N.

Of the optical fiber, an outer diameter of the inner clad
10 layer is 90μm in terms of optical fiber diameter, thickness of
the high viscosity clad layer is 17.5μm in terms of optical fiber,
viscosity V_0 of the high viscosity clad layer at the temperature
T_s is 7.9[log(poise)]. Rise of the OH peak of 0.014dB/km is
measured, after this optical fiber is exposed to atmosphere
15 containing 1% hydrogen for four days.

[Example 3]
The step index type single mode optical fiber as shown in
Fig.5, of which outer diameter is 125μm, difference of relative
20 index of refraction is 0.34%, mode field diameter at wavelength
of 1385nm is 10μm, is manufactured by forming clad of periphery
of the core in inside area with glass which has the same composition
as the inner clad layer in outside area, and drawing the preform
having two layers of the inner clad layer and the high viscosity
25 clad layer in outside area at drawing speed of 800m/min and drawing
tension of 1.4N.

Of the optical fiber, an outer diameter of the inner clad
layer is 80μm in terms of optical fiber diameter, thickness of
30 the high viscosity clad layer is 22.5μm in terms of optical fiber,
viscosity V_0 of the high viscosity clad layer at the temperature
T_s is 7.9[log(poise)]. After this optical fiber is exposed to

atmosphere containing 1% hydrogen for four days, rise of the OH peak is measured, but no rise is recognized at all.

[Example 4]

5   The step index type single mode optical fiber as shown in Fig.5, of which outer diameter is 125μm, difference of relative index of refraction is 0.34%, mode field diameter at wavelength of 1385nm is 10μm, is manufactured by forming clad of periphery of the core in inside area with glass which has the same composition

10   as the inner clad layer in outside area, and drawing the preform having two layers of the inner clad layer and the high viscosity clad layer in outside area at drawing speed of 800m/min and drawing tension of 1.4N.

15   Of the optical fiber, an outer diameter of the inner clad layer is 35μm in terms of optical fiber diameter, thickness of the high viscosity clad layer is 45μm in terms of optical fiber, viscosity V_0 of the high viscosity clad layer at the temperature T_s is 7.9[log(poise)]. After this optical fiber is exposed to

20   atmosphere containing 1% hydrogen for four days, rise of the OH peak is measured, but no rise is recognized at all.

[Example 5]

The step index type single mode optical fiber as shown in
25   Fig.5, of which outer diameter is 125μm, difference of relative index of refraction is 0.34%, mode field diameter at wavelength of 1385nm is 10μm, is manufactured by forming clad of periphery of core in inside area with glass which has the same composition as the inner clad layer in outside area, and drawing the pre-form

30   having two layers of the inner clad layer and the high viscosity clad layer in outside area at drawing speed of 800m/min and drawing tension of 1.4N.

Of the optical fiber, an outer diameter of the inner clad layer is 80μm in terms of optical fiber diameter, thickness of the high viscosity clad layer is 22.5μm in terms of optical fiber, viscosity V_0 of the high viscosity clad layer at the temperature T_s is 8.5[log(poise)]. After this optical fiber is exposed to atmosphere containing 1% hydrogen for four days, rise of the OH peak is measured, but no rise is recognized at all.

[Comparative Example 1]

The step index type single mode optical fiber as shown in Fig.6, of which outer diameter is 125μm, difference of relative index of refraction is 0.34%, mode field diameter at wavelength of 1385nm is 10μm, is manufactured by drawing a normal pre-form that the whole of clad is formed with the same material as clad of periphery of the core at drawing speed of 800m/min and drawing tension of 1.4N.

Rise of the OH peak of 0.105dB/km is measured, after this optical fiber is exposed to atmosphere containing 1% hydrogen for four days.

[Example 6]

The step index type single mode optical fiber as shown in Fig.5, of which outer diameter is 125μm, difference of relative index of refraction is 0.34%, mode field diameter at wavelength of 1385nm is 10μm, is manufactured by forming clad of periphery of core in inside area with glass which has the same composition as the inner clad layer in outside area, and drawing the pre-form having two layers of the inner clad layer and the high viscosity clad layer in outside area at drawing speed of 500m/min and drawing tension of 1.4N.

Of the optical fiber, an outer diameter of the inner clad layer is 100μm in terms of optical fiber diameter, thickness of the high viscosity clad layer is 12.5μm in terms of optical fiber,

5 viscosity V_0 of the high viscosity clad layer at the temperature T_s is 7.9[log(poise)]. Rise of the OH peak of 0.011dB/km is measured, after this optical fiber is exposed to atmosphere containing 1% hydrogen for four days.

10 [Comparative Example 2]

The step index type single mode optical fiber as shown in Fig.6, of which outer diameter is 125μm, difference of relative index of refraction is 0.34%, mode field diameter at wavelength of 1385nm is 10μm, is manufactured by drawing the normal optical

15 fiber pre-form that the whole of clad is formed with the same material as clad of periphery of the core at drawing speed of 500m/min and drawing tension of 1.4N.

Rise of the OH peak of 0.060dB/km is measured, after this

20 optical fiber is exposed to atmosphere containing 1% hydrogen for four days.

[Example 7]

The step index type single mode optical fiber as shown in

25 Fig.5, of which outer diameter is 125μm, difference of relative index of refraction is 0.34%, mode field diameter at wavelength of 1385nm is 10μm, is manufactured by forming clad of periphery of core in inside area with glass which has the same composition as the inner clad layer in outside area, and drawing the pre-form

30 having two layers of the inner clad layer and the high viscosity clad layer in outside area at drawing speed of 150m/min and drawing tension of 1.4N.

Of the optical fiber, an outer diameter of the inner clad layer is 100μm in terms of optical fiber diameter, thickness of the high viscosity clad layer is 12.5μm in terms of optical fiber, viscosity V_0 of the high viscosity clad layer at the temperature T_s is 7.9[log(poise)]. After this optical fiber is exposed to atmosphere containing 1% hydrogen for four days, rise of the OH peak is measured, but no rise is recognized at all.

[Comparative Example 3]

The step index type single mode optical fiber as shown in Fig.6, of which outer diameter is 125μm, difference of relative index of refraction is 0.34%, mode field diameter) at wavelength of 1385nm is 10μm, is manufactured by drawing the normal optical fiber pre-form that the whole of clad is formed with the same material as clad of periphery of the core at drawing speed of 150m/min and drawing tension of 1.4N.

Rise of the OH peak of 0.042dB/km is measured, after this optical fiber is exposed to atmosphere containing 1% hydrogen for four days.

[Example 8]

The step index type single mode optical fiber as shown in Fig.7, of which outer diameter is 125μm, difference of relative index of refraction is 0.34%, mode field diameter at wavelength of 1385nm is 10μm, is manufactured by forming clad of periphery of core in inside area with glass which has the same composition as the inner clad layer in outside area, and drawing the pre-form having three layers of the inner clad layer, the high viscosity clad layer, and the outside low viscosity clad layer in outside area at drawing speed of 800m/min and drawing tension of 1.4N.

Of the optical fiber, an outer diameter of the inner clad layer is 105µm in terms of optical fiber diameter, thickness of the high viscosity clad layer is 7µm in terms of optical fiber,

5   thickness of the outside low viscosity clad layer is 3µm in terms of optical fiber, viscosity V_0 of the high viscosity clad layer at the temperature T_s is 8.5[log(poise)], viscosity V_t of the outside low viscosity clad layer at the temperature T_s is 7.6[log(poise)]. 1% proof test on the optical fiber is conducted, but no disconnection

10 of fiber is found.   Furthermore after this optical fiber is exposed to atmosphere containing 1% hydrogen for four days, rise of the OH peak is measured, but no rise is recognized at all.

In addition, in the present example the reason why there

15 are no disconnection of the fiber regardless of thickness of the high viscosity clad layer of 7µm is because the outside low viscosity clad layer is formed the most outside of the clad.

[Comparative Example 4]

20 The step index type single mode optical fiber as shown in Fig.5, of which outer diameter is 125µm, difference of relative index of refraction is 0.34%, mode field diameter at wavelength of 1385nm is 10µm, is manufactured by forming clad of periphery of core in inside area with glass which has the same composition

25 as the inner clad layer in outside area, and drawing the pre-form having two layers of the inner clad layer and the high viscosity clad layer in outside area at drawing speed of 800m/min and drawing tension of 1.4N.

30 Of the optical fiber, an outer diameter of the inner clad layer is 111µm in terms of optical fiber diameter, thickness of the high viscosity clad layer is 7µm in terms of optical fiber,

viscosity V0 of the high viscosity clad layer at the temperature Ts is 8.5[log(poise)]. In the case of winding back operation this optical fiber, the optical fiber breaks, and many breakage inside of remaining optical fiber are also recognized. Because the

5   outside low viscosity clad layer is not formed on the most outside of the clad, the optical fiber is broken.

In addition, the results explained above as examples 1-8 and comparative examples 1-4 are shown below as table 1.

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TABLE 1

	V_0 log(poise)	Inner clad diameter μm	Thickness of high viscosity clad μm	Thickness of outside low viscosity clad μm	Drawing tension N	Drawing speed m/min	OH peak rise dB/km
Example 1	7.9	100	12.5	0	1.4	800	0.03
Example 2	7.9	90	17.5	0	1.4	800	0.014
Example 3	7.9	80	22.5	0	1.4	800	no rise
Example 4	7.9	35	45	0	1.4	800	no rise
Example 5	8.5	80	22.5	0	1.4	800	no rise
Comparative example 1	7.6	125	0	0	1.4	800	0.105
Example 6	7.9	100	12.5	0	1.4	500	0.011
Comparative example 2	7.6	125	0	0	1.4	500	0.060
Example 7	7.9	100	12.5	0	1.4	150	no rise
Comparative example 3	7.6	125	0	0	1.4	150	0.042
Example 8	8.5	105	7	3	1.4	800	no rise
Comparative example 4	8.5	111	7	0	1.4	800	break

As clear from the above explanation, according to the present embodiment, even if the optical fiber obtained by drawing the

15   pre-form is exposed to hydrogen atmosphere, the OH peak in the fiber at wavelength about 1385nm hardly rises regardless of condition of drawing.

Although the present invention has been described by way of exemplary embodiments, it should be understood that those skilled in the art might make many changes and substitutions without departing from the spirit and the scope of the present invention which is defined only by the appended claims.